AD-A180 143 EFFECT OF SHADOWS ON THE REFLECTANCE SPECTRA OF VEGETATION AND THEIR DIGI..(U) ARMY ENGINEER TOPOGRAPHIC LABS FORT BELVOIR VA 1/1

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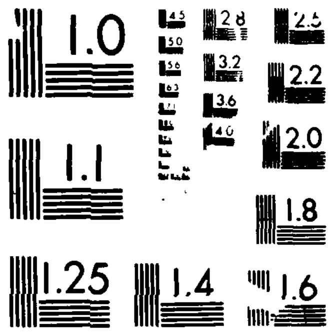

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These results are directly applicable to Army tasks involving the detection of change in terrain conditions by means of multi-date, multi-spectral imagery. The use of band ratio techniques or imagery adjustments for shadow must consider the effect of solar altitude on the reflectance spectra of different colored vegetation in the vegetation-soil mosaic.

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ABSTRACT:

Change in solar altitude alters the reflectance spectra of the plant canopy by affecting the highlight/shadow ratio of the canopy. The reflectance spectra of canopies with high contrast between sunlit and shaded leaves had a strong, direct relation with solar altitude, e.g., the visible and NIR regions of gray colored plants and the NIR region for green colored plants. Canopies with low reflectance contrast did not have a strong relation with solar altitude, e.g., the visible region for green plants. The anisotrophic effect of solar altitude on the visible and NIR reflectance varied the NIR/Red and Normalized Difference Vegetation Index ratios, commonly associated with plant productivity parameters. These ratios varied inversely with solar altitude.

These results are directly applicable to Army tasks involving the detection of change in terrain conditions by means of multi-date, multi-spectral imagery. The use of band ratio techniques or imagery adjustments for shadow must consider the effect of solar altitude on the reflectance spectra of different colored vegetation in the vegetation-soil mosaic. The multi-temporal spectral imagery should be normalized for the vegetation spectral differences associated with solar altitude differences that occur daily, seasonally, or latitudinally.

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EFFECT OF SHADOWS ON THE REFLECTANCE SPECTRA OF VEGETATION AND THEIR DIGITAL CLASSIFICATION

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Change in solar altitude and azimuth can substantially alter the reflectance spectra of the vegetation-soil mosaic. Aside from atmospheric considerations, solar irradiance varies in quality and quantity with solar altitude which varies diurnally, seasonally, and with latitude. Some direct results from change in solar altitude are alterations of the percentages of shaded and sunlit vegetation in the plant canopy, as well as the percentages of shaded and sunlit vegetation and soil in the vegetation-soil mosaic. Although the relations between solar altitude, solar azimuth, and solar time are well documented in standard astronomical tables and algorithms, the relations between solar altitude, plant canopy structure, shadow patterns, and reflectance changes have not been developed.

The shadow effect has two levels; a general level concerned with the percentages of sunlit and shaded vegetation and soil in the vegetation-soil mosaic, and a detailed level concerned with the percentages of sunlit and shaded vegetation within the plant canopy. The general level describes the percentages of sunlit and shaded vegetation and soil using the various factors of the plant canopy/radiometer/illumination model. These computations assume an opaque plant canopy and uniform soil surface conditions (2). The detail level is difficult to model because the canopy has a number of variables that are poorly defined. First, the numbers of each of the component parts, i.e., leaves, stems, and branches, can vary between the canopies of the same species and between different plant species. There is variation in the surface structure of each part, i.e., the leaf surface can be smooth, crenulated, wrinkled, waxy, or hairy; each of which has its own diffuse and specular scattering properties and each can introduce a fine shadow detail within the surface. There is variation in the size, shape, and arrangement of the components parts, which alters the shadow structure as well as the volume scattering properties of the canopy. There is variation in the spectral reflectance and transmittance properties of the different surfaces and materials, i.e., leaf, twig, or stem; young leaf or old leaf; and topmost leaf or bottommost leaf. Finally, all of these factors can vary as a function of species, plant vigor, and geographic location.

Other things being equal, the light reflected from a sunlit or a shaded area in the plant canopy depends on the characteristics of the light illuminating the area and the reflectance, transmittance, and absorptance characteristics of the material. Shaded areas can be illuminated directly by skylight or by the sunlight and skylight that are transmitted through translucent materials or scattered from surfaces outside of the canopy. Some plant parts, particularly woody stems and branches, are opaque and their shadows are illuminated by light scattered from adjacent surfaces. Other plant parts, such as leaves, can be opaque in one spectral region and translucent in another, and contribute at least a small component of transmitted light to their shadows in addition to any scattered light.

Objective.

To determine if there are reliable relations between the reflectance spectra of semiarid plant canopies and solar altitude that can be used for modeling and to support digital anlaysis procedures of multi-spectral imagery.

Materials and Procedures.

Spectral measurements were made of selected plant canopies at six field study sites in Arizona and Nevada. Four semiarid shrubs, 30 to 80 cm tall, were measured: bursage, *Ambrosia dumosa*; greasewood, *Sarcobatus vermiculatus*; sagebrush, *Artemisia tridentata*; and shadscale, *Atriplex confertifolia*. Two herbaceous plant covers, 40 to 80 cm tall, were also measured: legume-grass, *Thermopsis montana* and *Poa* sp.; and alfalfa, *Medicago* sp. The plants selected were uniform in height and leaf cover, and were not flowering. All plants appeared vigorous and did not exhibit obvious plant stress.

The spectra of the Halon reference standard, sunlit vegetation, and shaded vegetation were measured using a scanning spectroradiometer with a 15 degree field of view. The spectra were measured over the 360nm to 1100nm region in 10nm bandpasses, between 0730 and 1400 true solar time. The plant canopy and the Halon were viewed vertically by the spectroradiometer. The plant surface in the radiometer's field of view (FOV) was the "same" except for the changes in the sunlit and shaded portions of the canopy caused by changes in solar altitude. Spectra were also taken of shaded plant canopies, i.e., all of the plant canopy in the radiometer's FOV, was within the shadow of an opaque object.

The vegetation spectra (Vx) were normalized to a Halon reference standard (Hx) using equation 1. The reflectance value (RV) was calculated for each 10nm bandpass (i) over the 360nm to 1100nm spectrum. The spectra of the Halon reference were taken within 5 minutes of the time (x) that the vegetation spectra were taken.

$$RVx(i) = [\ Vx(i)/Hx(i)\ ] * [\ Hm(i)/Hx(i)\ ] * 100\% \qquad \text{Equation 1.}$$

where: Vx = vegetation radiance value at time "x"
Hx = Halon radiance at time "x" + 5 minutes,
Hm = maximum Halon radiance in a 10nm bandpass for the sample set.

The canopy's mean reflectances in Landsat Thematic Mapper band 1 (450-520nm), band 2 (520-600nm), band 3 (630-690nm), and band 4 (760-900nm) were calculated for each reflectance spectrum. The relations between solar altitude and the species mean reflectance in each Thematic Mapper bandpass were computed using regression analysis.

The near infrared (NIR)/Red and Normalized Difference Vegetation Index ratios were calculated from equations 2 and 3, using the mean reflectance values in Thematic Mapper band 3 and band 4.

$$\underline{\text{NIR/Red Ratio}} = \text{Band 4 / Band 3} \qquad \text{Equation 2.}$$

$$\underline{\text{Normalized Difference Vegetation Index (NDVI) Ratio}} = (\text{Band 4} - \text{Band 3}) / (\text{Band 4} + \text{Band 3}) \qquad \text{Equation 3.}$$

Results.

The reflectance spectra of bursage, greasewood, sagebrush, shadscale, legume-grass, and alfalfa are shown in Figures 1, 2, 3, 4, 5, and 6. The reflectances of the sunlit canopies increased directly with solar altitude, although each sunlit canopy contained some shaded areas. The magnitude of the reflectance contrast between sunlit and shaded portions of the canopy is shown by comparing the spectra of the shaded canopy to the sunlit canopy spectra.

In the visible region, the canopy reflectances of the alfalfa and legume-grass did not show a strong direct relation to solar altitude. A slight increase, 1-4 percent (absolute basis), in visible reflectance was found, which is probably transmitted energy that was reflected from the lower surfaces. The reflectances of bursage, greasewood, sagebrush, and shadscale were strongly and directly related to solar altitude. The visible reflectance increased 4-11 percent, primarily from the high reflectance contrast between sunlit and shaded leaves and the increased percentage of sunlit leaves. Some of the increased reflectance could be due to transmitted energy that is reflected from lower surfaces, but this would be a small percentage.

In the NIR region, reflectances of the vegetation types varied directly with solar altitude, except the legume-grass. The alfalfa's reflectance increased 30 percent (relative basis) as solar altitude increased from 30 to 70 degrees. The relative increase of the other plant's reflectance was smaller: bursage, 26 percent; greasewood, 26 percent; sagebrush, 10 percent; and shadscale, 20 percent. The legume-grass did not increase over its sample period. Statistical analysis shows that the reflectance differences in the visible region were not sigificantly different at the 95% level of confidence. In the NIR region significant differences were found for bursage spectra taken before 0950 true solar time and for the other vegetation types for spectra taken before 0900 true solar time.

The direct relations between the mean reflectances in a Thematic Mapper band and solar altitude are described by the regression curves (solid lines) in Figure 7. The number associated with a species identifies the appropriate regression curve, bursage (#1); greasewood (#2); sagebrush (#3); shadscale (#4); legume-grass (#5); and alfalfa (#6). Each regression curve has an R square value >0.96, except for the legume-grass curve, which had R square values >0.70. The legume-grass canopy was sampled between 1000 and 1300, which was not adequate for predicting canopy reflectance spectra for the early morning.

The NIR/Red and NDVI ratios associated with each species are presented in Figure 8. The species numbers are the same as those used in Figure 7. The lengths of the vertical lines indicate the range of the ratio values and the horizontal lines indicate the maximum, minimum, and mean ratio values for each vegetation type. The ratios varied as the visible and NIR reflectance contrast for the canopy varied with solar altitude. Close inspection of the spectral curves in Figures 1 to 4 shows that the relative reflectance of these plants increased slightly more in the visible region than in the NIR region over the sample period.

These ratios grouped vegetation into one of three groups;

a) green colored species, legume-grass (#5) and alfalfa (#6), that have the highest ratio values;

b) greenish-gray, bursage (#1) and yellow-green greasewood (#2), that have intermediate ratios, and

c) gray colored species, sagebrush (#3) and shadscale (#4), that have the lowest ratios.

Discussion.

The shadows in the vegetation-soil mosaic result from the interaction of many parameters of the plant canopy/radiometer/illumination model. Some parameters, such as plant growth, changed slowly while other parameters changed rapidly, e.g., solar altitude. The rapidly changing parameters are more of an immediate concern, because they, in part, affect the spectral characteristics of the vegetation-soil mosaic in remotely sensed imagery acquired over a short time.

The plant canopy spectra show substantial differences within the same vegetation type, as well as between the six vegetation types. These differences result from solar altitude effects and from the reflectance, transmittance, and absorptance characteristics of the plant canopy. The visible reflectance spectra of alfalfa and legume-grass, which have strong absorptances and low transmittances were seldom affected by changing highlight/shadow ratios caused by solar altitude changes. Alfalfa has high absorptance in the visible region and its reflectance varied only slightly, although the solar altitude ranged from 42 to 74 degrees. The plants that have less absorptance and high reflectance contrast between sunlit and shaded leaves, have strong direct reflectance-solar altitude relations. For example, the visible and the NIR reflectance spectra of sagebrush and shadscale increase directly with solar altitude, which decreased the shaded areas of the canopy surface.

In the NIR region, the leaf's reflectance and transmittance properties are important because they influence the amount of energy going into and reflecting from the shaded areas of the plant canopy. The transmitted energy on reaching the shaded leaf layer is reflected, absorbed, or transmitted according to the properties of the leaf. The NIR reflectance contrast between the fully sunlit green leaf and the first shaded green leaf can be about 30 percent, assuming 50 percent reflectance and 40 percent transmittance. As the solar altitude increases, the percentage of sunlit leaves will increase and change the percentages of the shaded leaves categorized as second, third, and fourth leaf layers in the plant canopy, and concurrently the canopy reflectance will increase.

The bursage, greasewood, sagebrush, shadscale, and alfalfa spectra show high reflectance contrasts between the sunlit and shaded canopies, despite two conditions that tend to reduce the reflectance contrast. First, the size of the shadow cast on the plant canopy was only slightly larger than the radiometer's FOV when the shaded canopy spectra were measured, and some scattered sunlight may have been included in the NIR reflectance spectra for these plants. This is suspected because of relatively high levels of infrared that show in the spectra of the shaded canopy for some plants. Second, all "sunlit" canopies are a mosaic of sunlit and shaded surfaces, all of which were viewed by the radiometer. Even so, the NIR reflectance spectra of the sunlit and shaded canopies show that any shadows in the canopy will lower the NIR reflectance from that expected for a fully sunlit canopy.

The reflectance-solar altitude relations for the 6 vegetation types were summarized by the mean reflectances in the four Thematic Mapper bandpasses. In the visible bands, the reflectances of the green colored species increased 1-4 percent (absolute basis) and those for the gray colored species increased 4-11 percent. This is attributed to the absorptance of the leaves and the reflectance contrast between the sunlit and shaded portions of the plant canopy. Because of their higher visible reflectance, the gray plants varied substantially more with solar altitude than did the reflectance of the green plants. The visible reflectance for gray species increased from 50-70 percent (relative basis) which was near the levels expected from change in shadow length, i.e., about 79 percent; [Tan (70 degrees) - Tan (30 degrees)] / Tan (70 degrees). The reflectance of the green canopies increased very little because of their high absorptance in the visible region.

In the NIR region, the canopy reflectances of all plants varied directly with solar altitude. As the solar altitude changed from 30 to 70 degrees, the relative NIR reflectance of bursage increased about 57 percent (relative basis), greasewood, 26 percent; big sagebrush, 39 percent; shadscale, 53 percent; and alfalfa, 46 percent. The relative NIR reflectance increases were slightly smaller than those found in the visible region, because leaf transmittance in the NIR region, and subsequent reflectance from lower surfaces reduces the reflectance contrast between sunlit and shaded leaves.

The effects of solar altitude on the NIR/Red and NDVI ratios resulted from the shadow effects on the visible and NIR reflectance. For the green canopies, legume-grass and alfalfa, the NIR/Red ratios varied substantially, because of the direct relation between NIR reflectance and solar altitude, which increased the red to near infrared reflectance contrast. The NIR/Red ratio varied slightly for the other vegetation types because the visible and NIR reflectances were about equally affected by changes in the shaded areas of the canopy. The NDVI ratio varied little for the green vegetation because of the low and almost constant visible reflectance. This reduced the NDVI ratio to essentially a NIR/NIR ratio. The NDVI ratios for the gray vegetation varied much more because of the visible and NIR reflectance changes associated with increased solar altitude. This varied the numerator and demoninator of the NDVI ratio, causing it to vary inversely with solar altitude. These effects are important because the ratios have been highly correlated with various plant growth parameters (1, 5, 7, and 8).

The canopy reflectance differences associated with changes in solar altitude can substantially affect the use of multi-date, multispectral imagery for monitoring the vegetation-soil mosaic at a given geographic location, or for monitoring a vegetation type in different latitudes. Monitoring the same area over several months should show reflectance differences in the vegetation-soil mosaic. Assigning levels of importance to these differences could be a difficult problem. Some of these differences will be associated with solar altitude effects on in-canopy shadows, which will vary the canopy reflectance. Other differences will be associated with change in percent ground cover, biomass or leaf area of the vegetation-soil mosaic (6 and 7). For example, the differences in the TM-4 band brightness values for alfalfa could suggest a doubling of the leaf area of the plant canopy, not the change in solar altitude that varied the percentages of sunlit and shaded vegetation in the sensor's FOV. Band ratios can remove some of the solar altitude effects but the ratio selected is dependent on the vegetation being considered. The NDVI ratio for green vegetation was slightly affected by shadowing, while the NIR/Red ratio was substantially affected. For the gray colored plants, the NIR/Red ratio was affected less than was the NDVI ratio. Whether a ratio for a specific vegetation type was affected depended on the plant's reflectance, absorptance, and transmittance characteristics in the visible-near infrared region.

Conclusions.

The visible-near infrared reflectance of the plant canopy varied directly with solar altitude, which affected the in-canopy shadows. In the spectral regions where plants had low reflectance contrast between sunlit and shaded canopies, the canopy reflectance differences were small as solar altitude decreased the in-canopy shadowed area. Vegetation types with large reflectance contrast between sunlit and shaded canopies had large reflectance differences.

NIR/Red and NDVI ratios varied with solar altitude and were affected by the reflectance contrast between sunlit and shaded vegetation. These ratios can be used to monitor vegetative change, but the diurnal, seasonal, and latitudinal effects of solar altitude on vegetation spectra must address reflectance differences associated with different colored vegetation. The ratios differentiated three vegetation groups for which the ratio values varied from high to low

green colored vegetation,
greenish-gray and yellowish-green colored vegetation,
gray colored vegetation.

Canopy reflectance differences were significant between the true solar noon spectra and those taken before 0930. Spectra taken after this time varied from the true solar noon spectra, but these differences became smaller as the spectra were taken closer to true solar noon.

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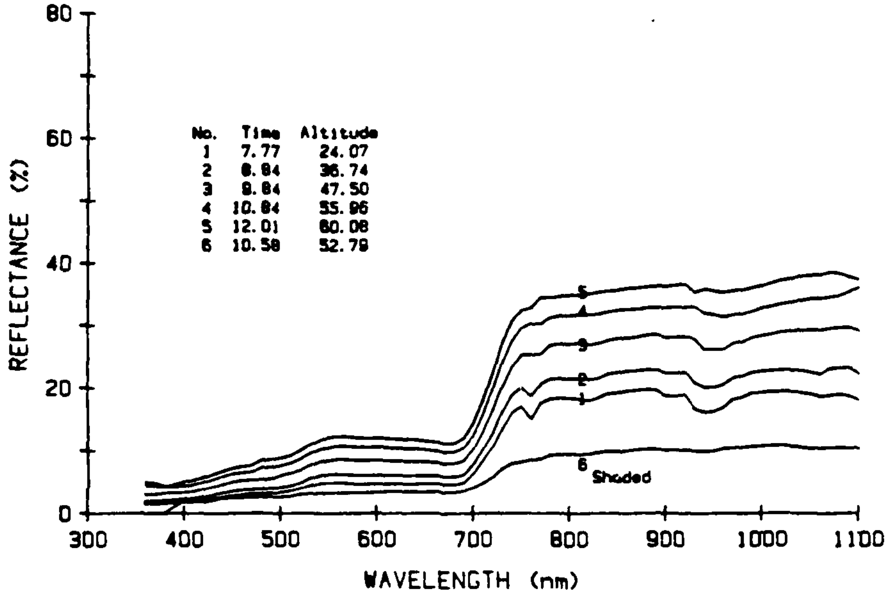

Figure 1. Reflectance Spectra of Sunlit and Shaded Bursage Canopies.

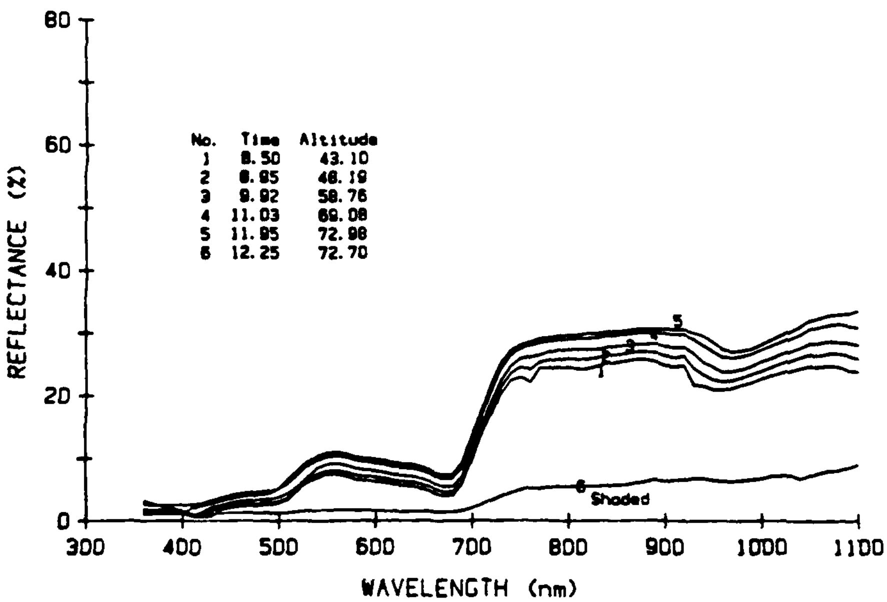

Figure 2. Reflectance Spectra of Sunlit and Shaded Greasewood Canopies

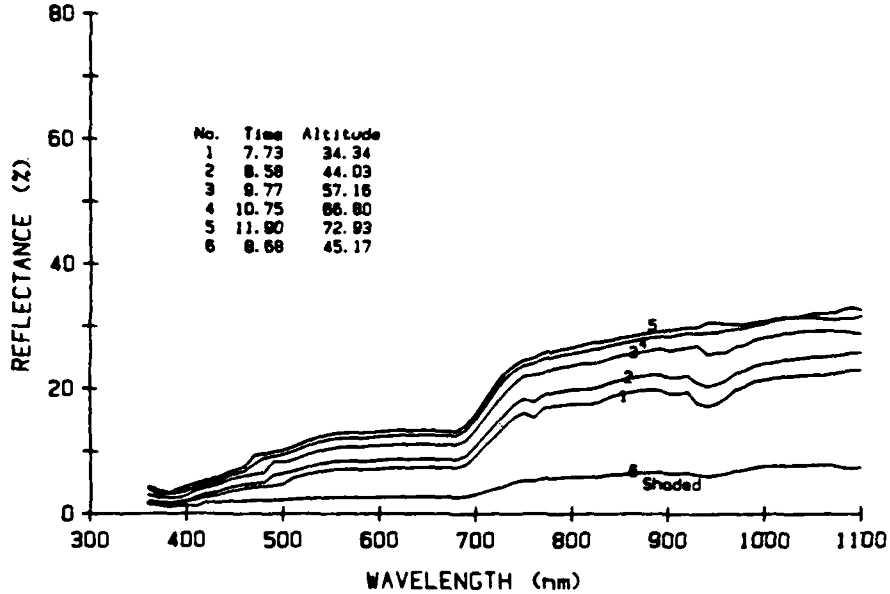

Figure 3. Reflectance Spectra of Sunlit and Shaded Big Sagebrush Canopies.

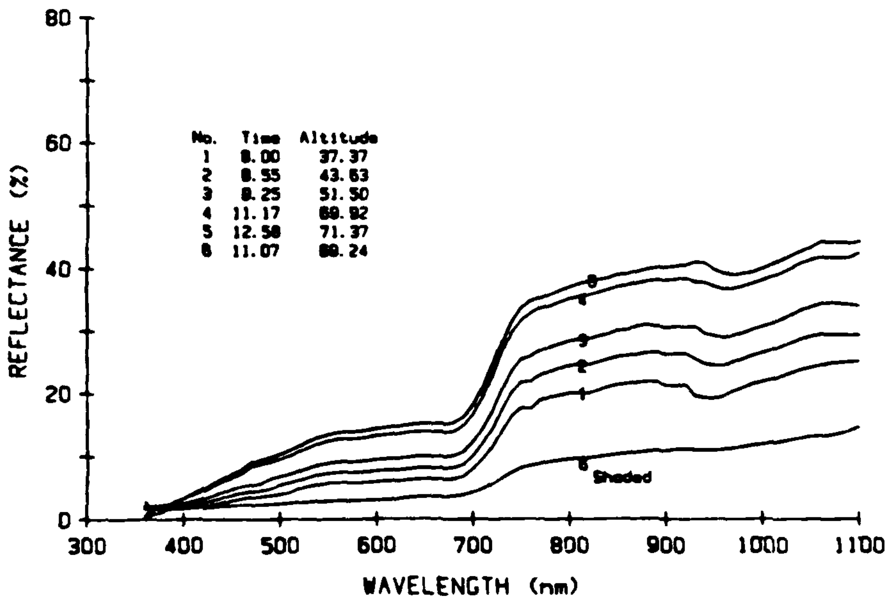

Figure 4. Reflectance Spectra of Sunlit and Shaded Shadscale Canopies.

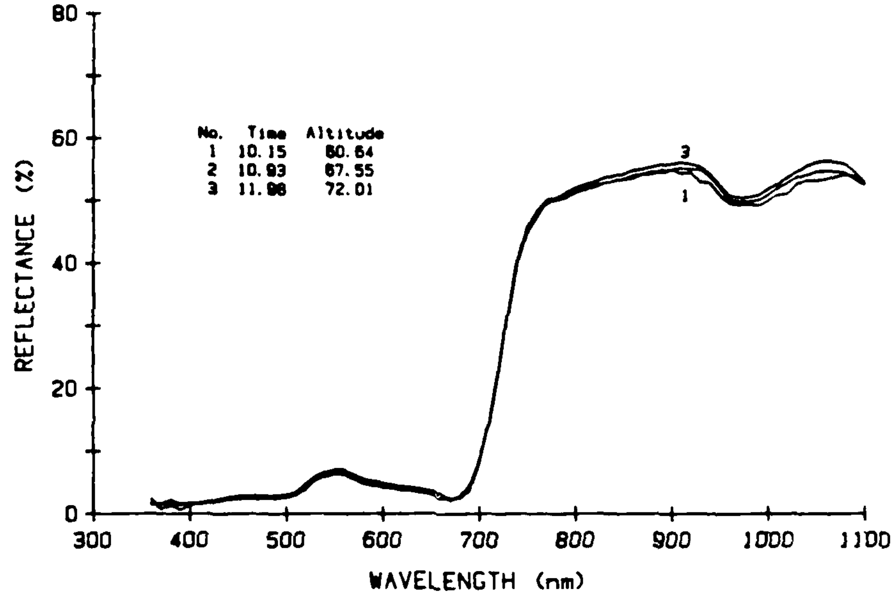

Figure 5. Reflectance Spectra of Sunlit Legume-Grass Canopy

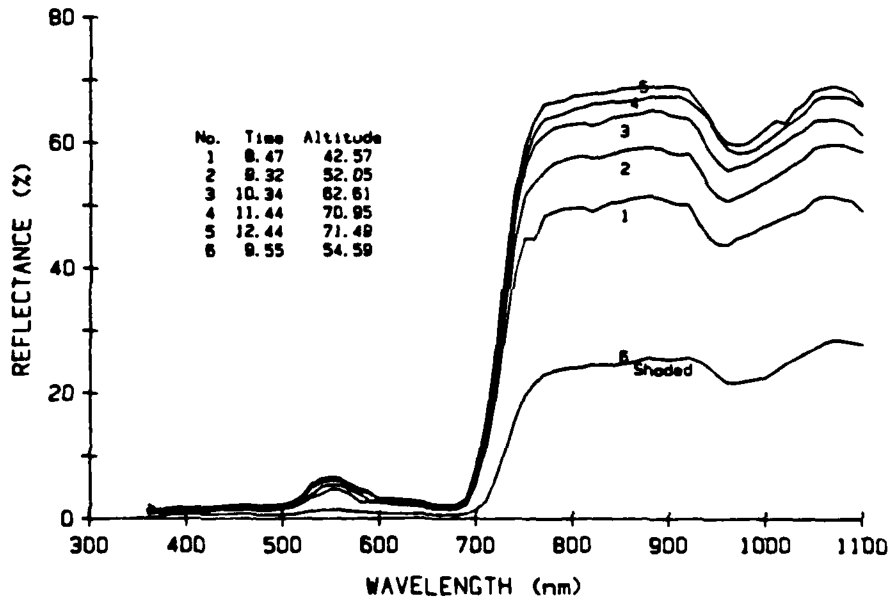

Figure 6. Reflectance Spectra of Sunlit and Shaded Alfalfa Canopies.

Bursage	(1)	$Y(X) = 5.036 - (0.163 \cdot X) + (0.0037 \cdot X^2)$	$R^2 = 0.982$
Greasewood	(2)	$Y(X) = 4.281 - (0.093 \cdot X) + (0.0014 \cdot X^2)$	$R^2 = 0.991$
Sagebrush	(3)	$Y(X) = 1.131 + (0.096 \cdot X) + (0.0002 \cdot X^2)$	$R^2 = 0.997$
Shadscale	(4)	$Y(X) = -1.486 + (0.137 \cdot X) + (0.0002 \cdot X^2)$	$R^2 = 0.995$
Legume-grass	(5)	$Y(X) = 25.237 - (0.722 \cdot X) + (0.0058 \cdot X^2)$	$R^2 = 0.755$
Alfalfa	(6)	$Y(X) = -0.498 + (0.058 \cdot X) - (0.0003 \cdot X^2)$	$R^2 = 0.978$

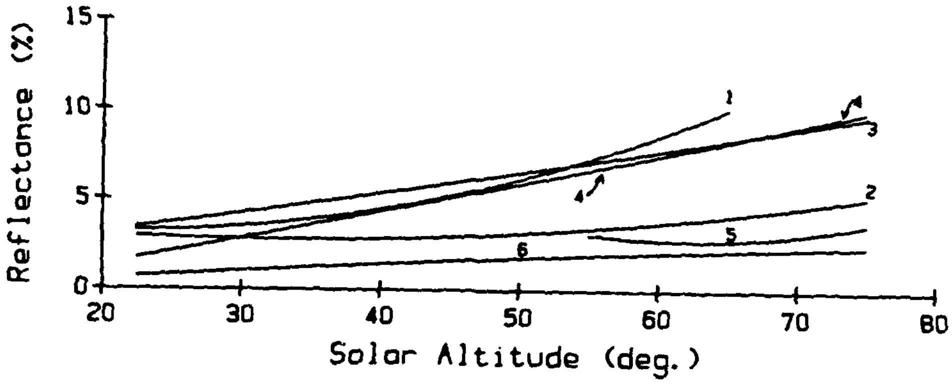

Figure 7a. Relation between Solar Altitude and Canopy Reflectance in Landsat TM BAND 1 (450-520nm)

Bursage	(1)	$Y(X) = 5.986 - (0.165 \cdot X) + (0.0044 \cdot X^2)$	$R^2 = 0.983$
Greasewood	(2)	$Y(X) = 4.418 + (0.018 \cdot X) + (0.0008 \cdot X^2)$	$R^2 = 0.994$
Sagebrush	(3)	$Y(X) = 0.472 + (0.201 \cdot X) - (0.0005 \cdot X^2)$	$R^2 = 0.997$
Shadscale	(4)	$Y(X) = -1.425 + (0.185 \cdot X) + (0.0003 \cdot X^2)$	$R^2 = 0.994$
Legume-grass	(5)	$Y(X) = 35.836 - (0.985 \cdot X) + (0.0079 \cdot X^2)$	$R^2 = 0.744$
Alfalfa	(6)	$Y(X) = -3.983 + (0.235 \cdot X) - (0.0015 \cdot X^2)$	$R^2 = 0.973$

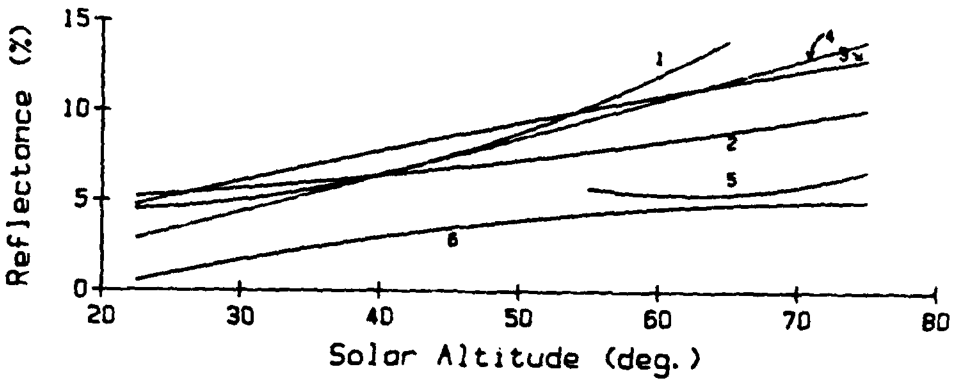

Figure 7b. Relation between Solar Altitude and Canopy Reflectance in Landsat TM BAND 2 (520-600nm)

Bursage	(1)	Y(X) =	5.821	- (0.150 * X)	+ (0.0042 * X^2)	R^2 =	0.984
Greasewood	(2)	Y(X) =	3.661	- (0.013 * X)	+ (0.0010 * X^2)	R^2 =	0.996
Sagebrush	(3)	Y(X) =	0.393	+ (0.225 * X)	- (0.0006 * X^2)	R^2 =	0.996
Shadscale	(4)	Y(X) =	-1.347	+ (0.200 * X)	+ (0.0004 * X^2)	R^2 =	0.993
Legume-grass	(5)	Y(X) =	24.311	- (0.694 * X)	+ (0.0057 * X^2)	R^2 =	0.723
Alfalfa	(6)	Y(X) =	-0.977	+ (0.083 * X)	- (0.0005 * X^2)	R^2 =	0.975

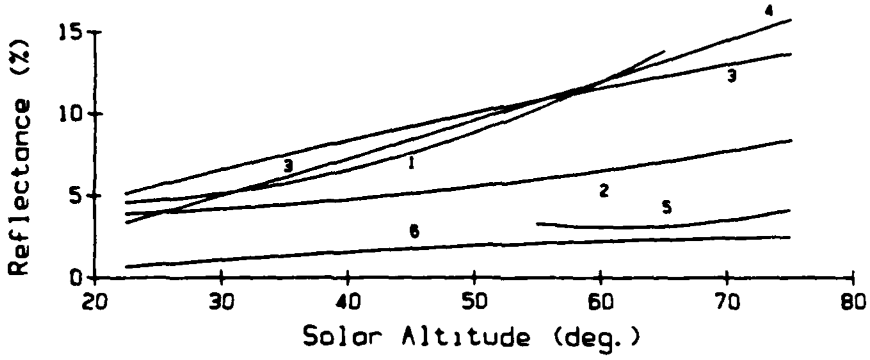

Figure 7c. Relation between Solar Altitude and Canopy Reflectance in Landsat TM BAND 3 (630-690nm)

Bursage	(1)	Y(X) =	20.195	- (0.306 * X)	+ (0.0095 * X^2)	R^2 =	0.984
Greasewood	(2)	Y(X) =	11.886	+ (0.385 * X)	- (0.0020 * X^2)	R^2 =	0.968
Sagebrush	(3)	Y(X) =	2.551	+ (0.542 * X)	- (0.0028 * X^2)	R^2 =	0.989
Shadscale	(4)	Y(X) =	-3.399	+ (0.754 * X)	- (0.0026 * X^2)	R^2 =	0.993
Legume-grass	(5)	Y(X) =	209.750	- (4.812 * X)	+ (0.0366 * X^2)	R^2 =	0.233
Alfalfa	(6)	Y(X) =	-11.571	+ (1.914 * X)	- (0.0114 * X^2)	R^2 =	0.980

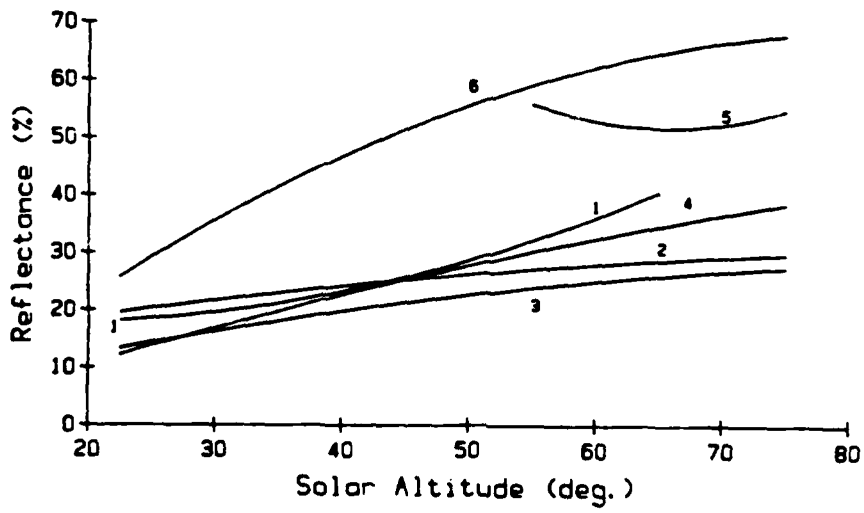

Figure 7d. Relation between Solar Altitude and Canopy Reflectance in Landsat TM BAND 4 (760-900nm)

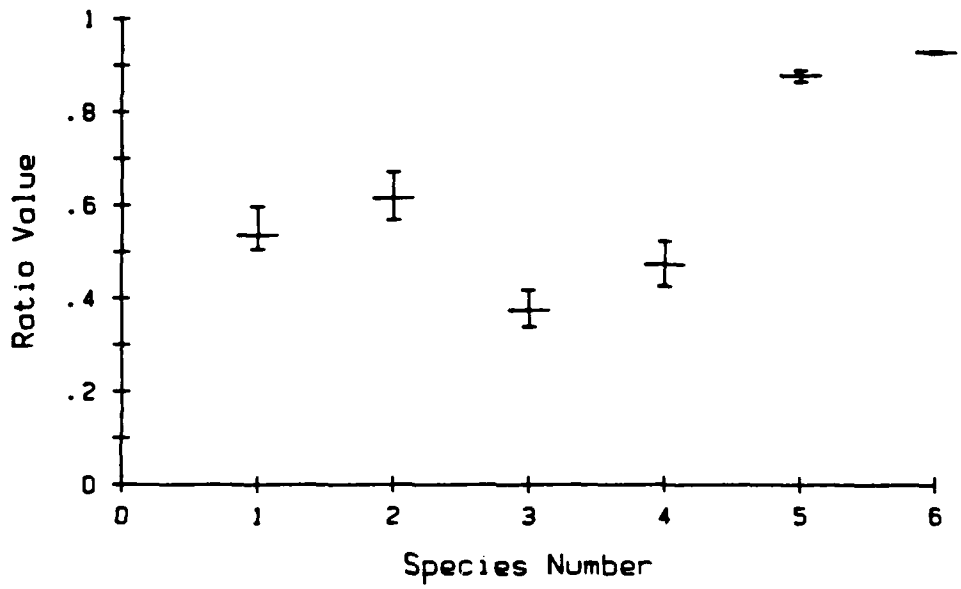

Figure 8b. Normalized Difference Vegetation Index for Vegetation Types

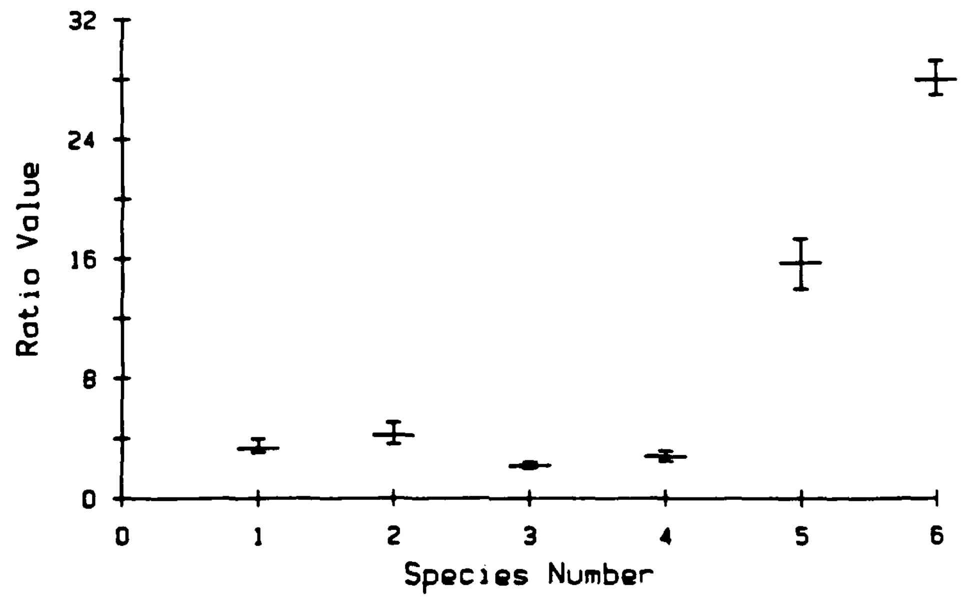

Figure 8a. NIR/Red Ratio for Vegetation Types

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